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The results of a detailed analysis performed on the data obtained in the $^{249}Cf + ^{48}Ca$ bombardment is presented. This analysis is independent of the original data analysis performed in Dubna in which two possible decay chains were found. The first decay chain consisted of an evaporation residue implantation followed by two alpha decays and then a spontaneous fission. The second decay chain consisted of an evaporation residue implantation followed by an immediate spontaneous fission event. This analysis confirms that the two interesting events are present in the data. A summary of the two events will be given as well as a description of the analysis performed.

I. INTRODUCTION

Past experiments by the Dubna-Livermore collaboration with ^{248}Cm and ^{244}Pu targets and high intensity ^{48}Ca beams led to the observation of isotopes of elements 116 and 114 [1-3]. Bolstered by the success of running experiments using intense beams of ^{48}Ca, a $^{249}Cf + ^{48}Ca$ bombardment was performed at FLNR, JINR, in 2002 in Dubna to look for the production of $^{294}118$ or $^{293}118$ [4]. Over the course of a six-month period, an accumulated beam dose of 2.5×10^{19} ^{48}Ca ions was obtained and two possible events that might be attributed to $^{294}118$ were observed. A summary of the two possible decay chains is given in Fig. 1. The energies and positions from Fig. 1 were calculated using calibrations performed in Dubna. In an attempt to confirm the results of the original data analysis, we performed a separate analysis on the 118 data.

II. CALIBRATION

To begin the independent analysis of the 118 data, we established the calibration parameters for all of the detectors. Each focal plane detector strip was calibrated for 9 parameters: slopes and intercepts for energy alpha, energy fission, position alpha, position fission and a correction factor for the fission energy. Each side detector was calibrated for 4 parameters: slopes and intercepts for energy alpha and energy fission.

The $^{nat}Yb + ^{48}Ca$ reaction was used to calibrate the alpha ranges for the focal plane and side detectors. A list of the prominent alpha peaks with their half-lives, alpha decay branches, and alpha decay energies for this reaction can be seen in Table 1.

The $^{206}Pb(^{48}Ca,2n)^{252}No$ reaction was used to check the alpha and fission calibrations. In addition to the multiple alpha decay peaks seen in the ^{nat}Yb + ^{48}Ca reaction, a pulser with two voltages, one exactly twice the voltage of the other, was used to obtain a more accurate calibration. The calibration parameters were obtained from the same routine as was used in the ^{248}Cm + ^{48}Ca reaction [5]. An alpha-calibration spectrum from the ^{nat}Yb + ^{48}Ca reaction data is shown in Fig. 2.

III. DATA ANALYSIS

Like the decay chains that originate from elements 114 and 116, the decay chains that originate from element 118 are expected to end in spontaneous fission as decay recedes away from the expected "Island of Stability" region dominated by α decay. The search for spontaneous fission events used the following parameters: fission energy between 145 and 300 MeV, no time-of-flight signal, and an energy signal in the focal plane detector. Twenty-one spontaneous fission events were found that satisfied these search criteria. Each spontaneous fission events is summarized in Table 2. Evaporation residue implantations that occurred within ±4 mm of the spontaneous fission event, had energy greater than 5 MeV, and occurred within the previous 10000 events (~2 minutes) were listed for each spontaneous fission. Of the 21 fission events listed in Table 2, only two fission events were correlated to evaporation residues within one second. The other 16 fissions had an average correlation time of 85.6 seconds. The two fissions that had the shortest correlation times were also the two fissions that had energies greater than 200 MeV. These two events were considered possible events resulting from the decay of element 118. The other 16 fissions were assigned to the decay of isotopes of Cm and Cf resulting from the target and transfer reactions with the target.

A more careful examination of the two higher energy fission events was performed to search for alpha decays that were also correlated in position to the recoil and the fission. The first fission event had two alpha decays in correlation with both the recoil implant and the fission. The second fission event occurred only 3.2 ms following the recoil implant and as a result of the short time difference had no alpha decays correlated with it. A summary of the details of the two events can be seen in Table 3. The second alpha event correlated with the first fission event was an escape alpha. Very little energy was deposited in the focal plane detector, making the determination of the absolute position and uncertainty in the position difficult. As a result, a correction to the escape alpha position and uncertainty in the position was needed.

By examining the difference in the centroid position for an escape alpha and evaporation residue correlations, we made this correction to the position of the escape alpha. It was observed that as the energy of an escape alpha increased, the centroid position moved closer to zero. In addition, the FWHM of the position distribution also decreased. For a full energy alpha in the focal plane detector, the expected FWHM was 1-2 mm. For the lowest energy alpha escapes, the FWHM was 7-11 mm. The change in the FWHM as a function of the escape alpha energy is shown in Fig. 3. For strip 3 the FWHM for escape alpha and recoil correlations is larger than in the focal plane detector as a whole. The first four strips of the detector had an overall energy resolution that was worse than the rest of the detector strips. The FWHM was also smaller for the ^{206}Pb + ^{48}Ca reaction than the ^{nat}Yb + ^{48}Ca reaction. As a result, the estimation of the FWHM for the ^{249}Cf + ^{48}Ca experiment was difficult. The FWHM also changed during the course of the experiment, as the detectors suffered more radiation damage the longer an experiment ran. The difference between the FWHM at the beginning of the experiment and the end can be seen in Fig. 4. From Figs. 3 and 4, exponential curve fits to the change in FWHM were obtained and used to correct the position of the escape alpha from the first event. Using the ^{nat}Yb + ^{48}Ca reaction and the entire focal plane detector, a correction of +2.97 mm was made to the 1.411 MeV escape alpha position. The uncertainty in the correlation was determined to be between 5.0 and 6.5 mm. The positions of the other alpha signals and the spontaneous fission signals were corrected in the same manner as has been described before [5].

IV. CONCLUSIONS

The current LLNL data analysis found the events from the original JINR data analysis in Dubna. Two possible 118 events were found in the data. Both events have an EVR (E_{EVR} > 5 MeV) correlated in position (±1.3 mm) to a spontaneous fission event (E_{SF} > 200 MeV). One of the events is correlated to a full energy alpha and an escape alpha. The other event is not correlated to any alpha events. A summary of the details of each correlation can be found in Fig. 5. The standard deviation for the position difference between evaporation residues and alphas was 0.73 mm for the first event. The standard deviation for the position difference between evaporation residues and fissions was 0.33 mm for the first event and 0.18 mm for the second event. The difference in the difference between the EVR and the SF in the first event is larger than 2σ. A thorough examination of the raw data and the two calibrations used to analyze the data (original Dubna calibration and LLNL calibration) showed that the difference in position between EVR and SF can be smaller. Although these two events look promising, more events similar to these are required before these events can be considered definitive.

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[1] Yu. Tu. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. S. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Yu. S. Tsyganov, G .G. Gulbekian, S. L. Bogomolov, B. N. Gikal, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, G. V. Buklanov, K. Subotic, M. G. Itkis, O. V. Ivanov, Y. E. Karelin, A. N. Tatarinov, K. J. Moody, J. F. Wild, N. J. Stoyer, M. A. Stoyer, C. A. Laue, and R. W. Lougheed, Phys. Rev. **C 63**, 011301R (2000).

[2] Yu. Tu. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. S. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Yu. S. Tsyganov, G .G. Gulbekian, S. L. Bogomolov, B. N. Gikal, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, G. V. Buklanov, K. Subotic, M. G. Itkis, K. J. Moody, J. F. Wild, N. J. Stoyer, M. A. Stoyer, and R. W. Lougheed, Phys. Rev. Lett. **83**, 3154 (1999).

[3] Yu. Tu. Oganessian, Vu. K. Utyonkov, Y. V. Lobanov, F. S. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Yu. S. Tsyganov, G .G. Gulbekian, S. L. Bogomolov, B. N. Gikal, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, G. V. Buklanov, K. Subotic, M. G. Itkis, O. V. Ivanov, K. J. Moody, J. F. Wild, N. J. Stoyer, M. A. Stoyer, and R. W. Lougheed, Phys. Rev. **C 62**, 041604R (2000).

[4] Yu. Tu. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. S. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Yu. S. Tsyganov, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, O. V. Ivanov, A. A. Voinov, K. Subotic, V. I. Zagrebaev, M. G. Itkis, K. J. Moody, J. F. Wild, M. A. Stoyer, N. J. Stoyer, C. A. Laue, D. A. Shaughnessy, J. B. Patin, and R. W. Lougheed, FLNR Internal Report, D7-2002-287 (2002).

[5] J. B. Patin, K. J. Moody, M. A. Stoyer, J. F. Wild, D. A. Shaughnessy, and N. J. Stoyer, LLNL Internal Report (2003).

[6] S. Y. F. Chu, L. P. Ekström, and R. B. Firestone, WWW Table of Radioactive Isotopes, http://nucleardata.nuclear.lu.se/nucleardata/toi/ (1999).

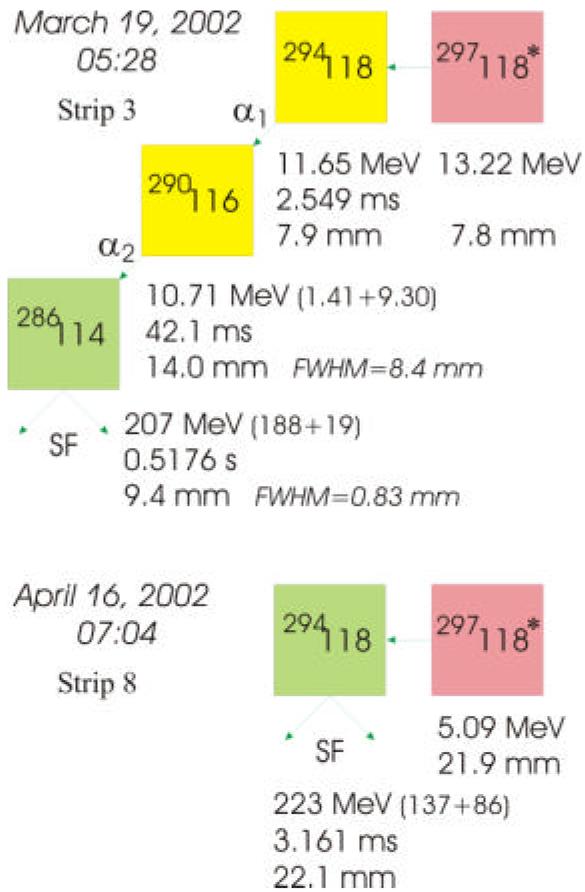

FIG. 1. Two possible decay chains from the $^{249}Cf(^{48}Ca,3n)^{294}118$ reaction performed in Dubna [4,5].

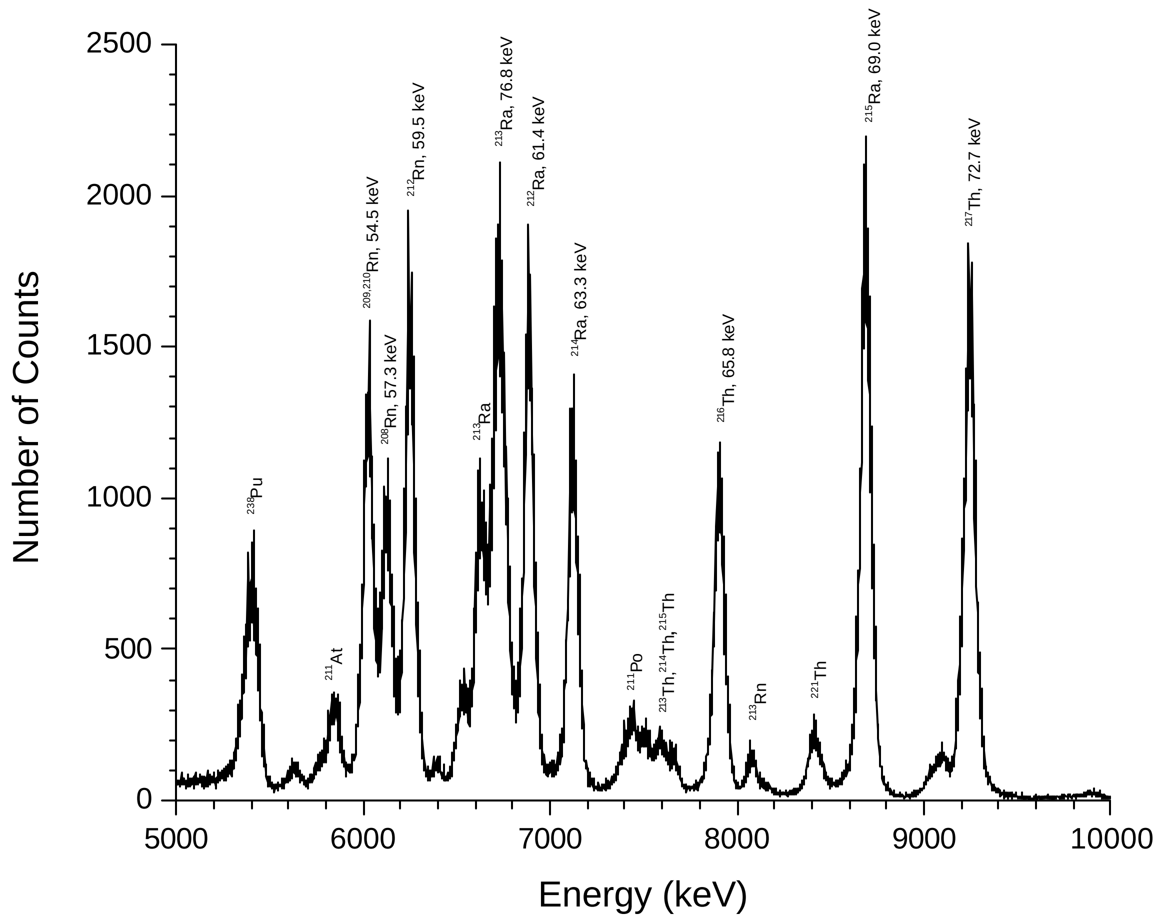

FIG. 2. Alpha spectrum from the ^{nat}Yb + ^{48}Ca calibration reaction. Alpha peak resolution (FWHM) given for the nine peaks used to determine the calibration parameter values.

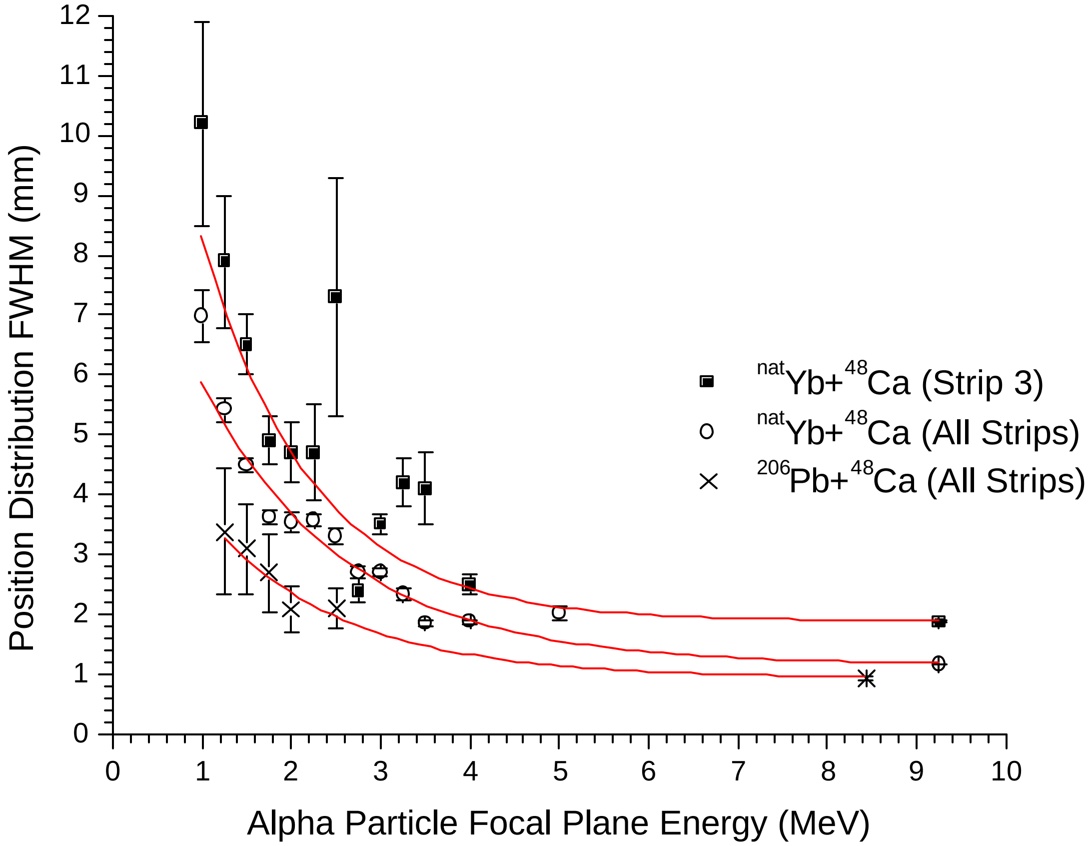

FIG. 3. The change in FWHM for the position distribution between a recoil and escape alpha as a function of escape alpha energy. The three lines represent exponential fits to the three indicated data sets. Position resolution for the 118 expected to lie between these three data sets.

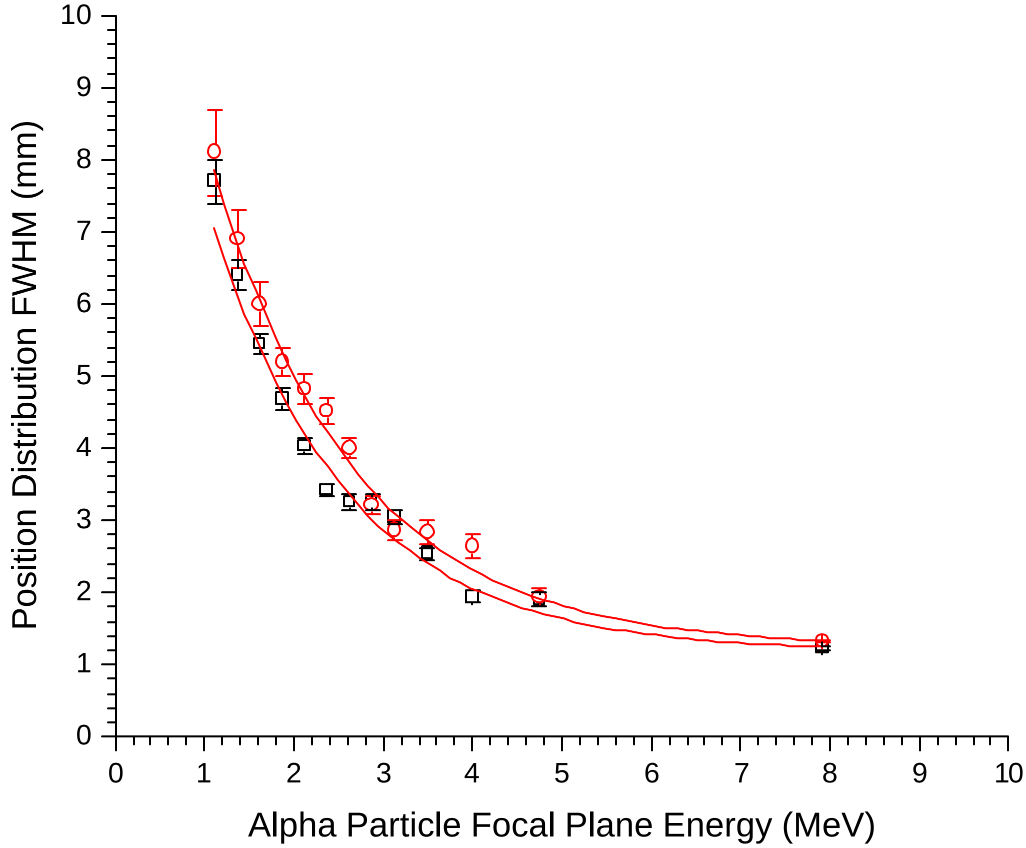

FIG. 4. The change in FWHM as a function of escape alpha energy and as a function of the progress of the experiment. The top line (?) represents the position resolution from the ^{nat}Yb + ^{48}Ca reaction from the end of the experiment, and the bottom line (?) represents the position resolution from the beginning of the experiment.

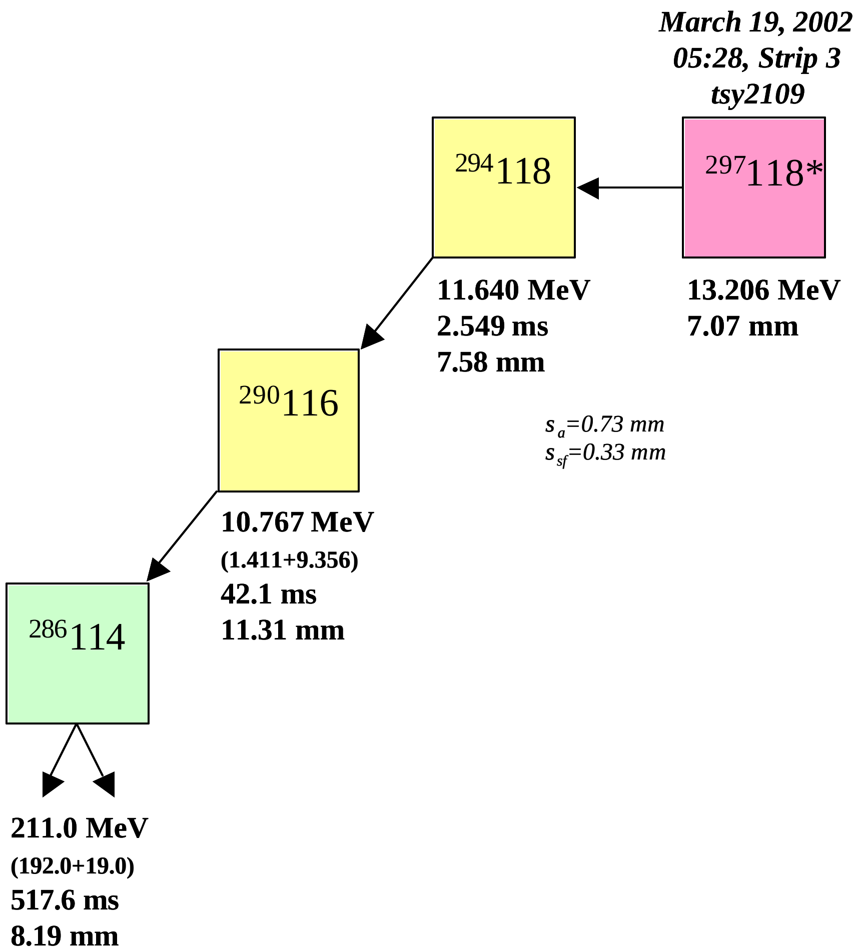

FIG. 5. Summary of the long possible decay chain originating from element 118. Signals detected in both the focal plane detector and the side detectors have their respective energies shown in parentheses.

TABLE 1. Decay data [6] for the isotopes found in the $^{nat}Yb + {}^{48}Ca$ reaction used in the alpha calibrations of the focal plane detector. Uncertainties in the last digit of the half-life, branching ratio, energies, and intensities are listed in parentheses.

Isotope	Half-life	α-Branch (%)	α-Energy (keV)	Intensity (%)
^{238}Pu	87.7(3) yr	100	5499.03(20)	70.91(10)
			5456.3(3)	28.98(10)
^{211}At	7.214(7) hr	41.80(8)	5869.5(22)	100
^{209}Rn	28.5(10) m	17(2)	6039(3)	99.62(2)
^{210}Rn	2.4(1) hr	96(1)	6040(2)	99.994(1)
^{208}Rn	24.35(14) m	62(7)	6143.8(21)	99.953(4)
^{212}Rn	23.9(12) m	100	6264(3)	99.950(5)
^{213}Ra	2.74(6) m	80(5)	6624(3)	49(2)
			6731(3)	45(2)
			6522(3)	6(1)
^{212}Ra	13.0(2) s	85	6899.2(17)	100
^{214}Ra	2.46(3) s	99.941(4)	7137(3)	100
^{211}Po	0.516(3) s	100	7450.3(5)	98.89(2)
^{215}Th	1.2(2) s	100	7395(8)	52(3)
			7524(8)	40(3)
^{213}Th	140(25) ms	100	7691(10)	100
^{214}Th	100(25) ms	100	7678(10)	100
^{216}Th	0.028(2) s	100	7921(8)	100
^{213}Rn	25.0(2) ms	100	8088(8)	99.0(5)
^{221}Th	1.68(6) ms	100	8146(5)	56(3)
			8472(5)	39(2)
^{215}Ra	1.59(9) ms	100	8699(4)	95.8(7)
^{217}Th	0.252(7) ms	100	9250(10)	100

TABLE 2. Summary of the spontaneous fission search. Event number from the beginning of the file. There are a total of 12 focal plane detector strips. Each detector strip has a position of 0-40 mm from the top of the strip to the bottom.

File	Buffer	Event	Strip	Energy (MeV)	Position (mm)
2035	386	122	4	151.53	7.78
2071	2575	45	1	164.70	36.36
2109	1374	108	3	210.95	10.36
2111	932	192	2	179.63	21.28
2176	224	4	9	149.78	13.36
2187	632	121	7	157.49	17.80
2195	791	110	4	150.48	38.01
2198	4434	254	4	145.82	33.40
2233	1390	20	8	213.27	21.40
2257	553	211	8	170.50	33.53
2284	482	251	1	150.14	14.39
2295	406	158	2	167.32	23.76
2300	1367	228	8	156.71	12.03
2306	3078	77	3	172.09	23.71
2312	1035	209	4	159.94	31.49
2321	1123	168	3	166.23	15.90
2334	382	18	4	184.35	21.59
2334	671	66	3	154.84	32.82
2354	1212	126	3	147.63	22.11
2419	742	109	7	159.80	34.16
2430	1177	28	12	193.52	1.96

TABLE 3. Summary of two possible correlated events from the decay of $^{294}118$.

Event #1

Isotope	Energy (MeV)	Position (mm)	ΔTime (ms)
EVR	13.206	7.07	
$^{294}118$	11.640	7.58	2.549
$^{290}116$	10.767 (1.411+9.356)	11.31	42.1
$^{286}114$	211 (192+19)	8.19	517.6

Event #2

Isotope	Energy (MeV)	Position (mm)	ΔTime (ms)
EVR		21.47	
$^{294}118$	213 (133+80)	21.40	3.161